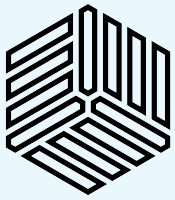

SEABORG

Why Seaborg Technologies has a unique and strong completive edge in the emerging world of Molten Salt Reactor (MSR) nuclear energy

The static & decoupled computation paradigm

In solid-fuelled reactors (all conventional nuclear reactors and all 4^{th} generation non-MSRs) the time governing the various aspects of the reactor physics are significantly different. Therefore, classical reactor designs safely relies on a strong decoupling of the involved scientific disciplines and thus allow for various aspects of the reactor dynamics to be probed independently.

(I) The **nuclear chain reaction** that generate the heat happens on millisecond and sub-millisecond time scale, this is simulated and studied using **neutronics** simulations.

(II) The **heat** is exchanged from the solid fuel (fuel rods) to the coolant fluid, typically water, and the coolant fluid is transported out of the core and into the external heat exchange system. This happens over a timescale in the range of several seconds. This process is studied using **hydro & thermodynamic calculations**.

(III) The coolant fluid is led into **heat exchangers and/or boilers and then into turbines** in a closed loop that feeds the water back into a condenser and then back to reactor core, this full cycle happens in a matter of minutes and is studied via **systems engineering**.

(IV) The fuel composition changes over weeks, due to transformation of fissionable elements, but it remains spatially static. This is simulated with **burnup** tools and often on a yearly basis the reactor is shut down and the fuel is rearranged while the reactor is at zero-power, this is calculated by **refuelling algorithms**.

(V) Occasionally fuel is extracted and is reprocessed, using **chemistry** calculations, however, spent reactor fuel is typically placed into containers and labelled "to be stored indefinitely".

All the various simulation situations above have historically been done by a multitude of software tools that are developed and refined over many years. These software tools are well known and regulatory bodies will always make sure that any reactor plant design has been thoroughly "verified" with these tools. For neutronics calculations the most well-known of such tools is MCNP.

The MSR coupled computational paradigm

In an MSR it is impossible to simulate a given design, using the above paradigm, for the following reasons:

(I) The fuel acts as the coolant fluid, this means that the thermodynamic, the thermo-hydraulics and the neutronic actions **all works at the same time scale**. They therefore constitute a strongly coupled system and cannot simply be calculated separately. While some thermo-hydraulics simulation software does exist, it has only been coupled to neutronics on academic level, and is not accepted by regulators.

(II) The fuel mixes constantly with itself (since it is a fluid in a dynamic system) and thus the changes from burnup cannot be considered static at all.

(III) Fission products, delayed neutron precursors in particular, are carried around in the fuel loop together with the liquid fuel in the reactor, which significantly complicates the neutronics calculations.

(IV) Most MSRs are designed to apply online refuelling and chemical reprocessing, since the fission processes slowly transforms nuclear fuel into undesired fission products, and transmutes different elements in the fuel-salt, which therefore changes the fuel composition while the reactor is operational.

(V) Lastly, a molten salt reactor is often designed to be controlled as a "slave to the turbine" (to enable its potential load-follow capabilities among other things), this means that the entire systems engineering process must be reversed and that the systems engineering will influence all the way back through the system and into the neutronics.

So how do you design such a complex dynamic system while also adhering to what the regulators consider their ultimate approved "reference' (i.e. the old legacy simulation and modelling software)?

The highly dynamic nature of MSRs requires that all the beforementioned computational disciplines must be coupled together in such a way that one can prove that a given design is technicallysolid, feasible and last but most importantly, safe. These methods are not well established by the existing reactor industry, which have been relying on the same tools for decades, with almost no evolution.

Reactor core analysis (neutronics) has a long story dating back to the advent of the first nuclear reactors in the 40ties. In general, neutronics is extremely computationally heavy and much focus has been - and still is - on simplifying the involved codes due to computational constraints.

Today there exist two main approaches to neutronics namely deterministic (semi-analytic) methods, which solve the Boltzmann transport equation in a numerically approximated manner, and Monte Carlo methods which takes a stochastic approach to neutron transport.
Conventionally, neutronics has been studied using deterministic methods, as they require much less computer resources than Monte Carlo approaches.

These methods are fast but provide a crude and not very accurate picture of what is going on in the reactor. On the other hand, Monte Carlo methodology give a much more accurate picture, as no approximations are required, but this also requires significantly more processor time.

Neutronics has therefore conventionally been a trade-off between minimizing raw computer time and maximizing accuracy. In Seaborg, we have realized that with today's super computers and parallel processing, and the even more powerful computers of tomorrow, this trade-off and the conventional deterministic codes used by the industry have become obsolete. It has therefore been paramount to base our software tools on accurate and regulator approved Monte Carlo methods to take full advantage of the capabilities of modern super computers.

This is what Seaborg Technologies specializes and excels in. We approach this tight coupling computational challenge with proven particle physics methodology combined with a very strong foundation in neutronics and complex physics - into a totally novel computational paradigm. In modern particle physics, modifying and coupling existing software while adding complex mathematics to "bind it together" is a core discipline.

We have developed a proprietary set of software tools that are able to "interconnect" between different simulations done with the various legacy software while also performing the highly complex math computations needed for simulating a molten salt reactor core, and all the surrounding systems.

Seaborg Technologies has taken the first steps into several areas in MSR simulations, making us world leading in the field. We currently provide our computational skills (but not our proprietary own software tools; those we keep in-house) to other MSR developers, and we are the first and currently only, producing MSR simulation of regulator acceptable quality, for one of the first-to-market MSR designs.

There is still much work to do before all the dynamic effects of a MSR is understood, and before MSRs can be proper licensed by regulators. This is our main field of expertise, we are world leading and we have been recognized internationally for this via our "world's first" demonstrations. We consider ourselves the only internationally pure-breed MSR design house mastering this.

On top of our world class simulation software skills we have also our own unique MSR reactor design, it is a small modular reactor design, and we are planning for a hard IP portfolio that will serve as not only protection for our own design but also to be sold (IP license model) as mission critical components to other MSR providers that are targeting different markets.

The current Seaborg Technologies Mark II reactor design is already included in the IAEA (International Atomic Energy Agency) 2016 book of Small Modular Reactor design "fit for further" development - a clear testimony to not only our computational skills but also our design and innovation talent.

Our new Mark III design is in progress and we have already filed our first core patent to this reactor.